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Effects of Cleaning of Coated Tedlar Samples on Space Environmental Performance

15 December 2000

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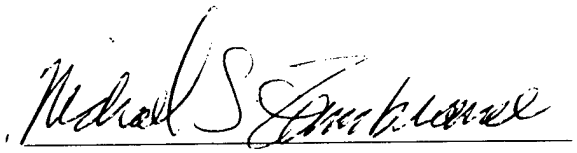

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13. ABSTRACT (*Maximum 200 words*)

A space environment exposure test has been performed on samples of Cloud White Tedlar with a multi-layer thin-film coating on the surface applied by Optical Coatings Laboratory, Inc. (OCLI) representing potential spacecraft applications. This test was performed to simulate a LEO ultraviolet (UV) exposure on a subset of samples representative of a piece of space hardware that had inadvertently been exposed to water. A test was needed to provide data on the amount of optical degradation that might be caused by cleaning the material surfaces and ascertain that the amount of degradation would be acceptable. Cleaning a damaged surface increases end-of-life solar absorptance by about 0.014. This suggests that over 90% of the coating remains in place. For thermal control surfaces installed on the hardware, this would result in an end-of-life solar absorptance of about 0.28 due to UV exposure. Other factors would also affect the end-of-life value.

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1. Introduction

Tedlar is a polyvinyl fluoride film produced by E. I. DuPont de Nemours & Co. (Inc.) with a variety of additives that can be introduced to produce different properties. The designation code of TWH is for a white Tedlar film, and a TCW designation is indicative of a Cloud White version that has a lower solar absorptance (is a whiter material). The full designation for these products, for example TCW20BE3, identifies color, thickness, surface finish, gloss, and type of elongation properties. Cloud White Tedlar with a multi-layer thin-film coating on the surface applied by Optical Coatings Laboratory, Inc. (OCLI) is being investigated for a number of potential spacecraft applications. Space environment exposure tests have been performed previously on a variety of samples exposed to simulated Low Earth Orbit (LEO) conditions.[1]

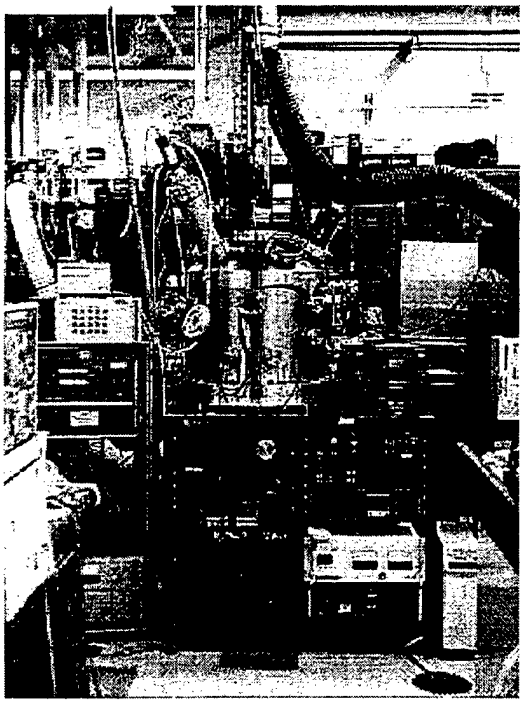
This test was performed to represent a LEO environmental exposure on a subset of samples representative of a piece of space hardware that had inadvertently been exposed to water. Previous work had shown that damage to the coating could occur with exposure to water. Damage to the coating would be expected to increase the solar absorptance due to ultraviolet (UV) exposure. Wiping of this surface as would be required in a cleaning procedure might further damage or remove the protective coating over the Tedlar. If the hardware were used as-is, cleaning might be required with isopropyl alcohol. In addition, sampling for the presence of unacceptable levels of non-volatile residue (NVR) would require a wipe of the hardware with an ethyl acetate solvent wipe. A test was needed to provide data on the amount of degradation caused by further cleaning of the material and ascertain that the amount of degradation would be acceptable for the mission.

Representative samples that had been cleaned with these solvents were compared with uncleaned samples. The samples were exposed to an environment corresponding to about five years solar UV at a LEO orbit. Selected samples were removed periodically during the exposures to measure the degradation changes as a function of time. All samples were removed for solar absorptance end-of-life measurements and compared with the degradation from previous studies of coated Tedlar tested to a 5-year LEO exposure.

2. Experimental

The Space Environmental Effects Chamber (Figure 1) used to provide the simulation of the LEO space environment contains a 2500-W xenon arc lamp for long-wavelength UV (230–400 nm) and a 150-W deuterium arc lamp for vacuum ultraviolet (VUV) radiation (115–200 nm). The UV beams have a uniformity within 50% but contain small, central hot spots. Both beams are confocal. The chamber is turbopumped and cryopumped, and the base pressure is 3×10^{-9} torr. The volume is roughly 200 liters, with a sample table 12 in. in diameter capable of temperature control from −150°C to +150°C, but kept at about 25°C for these tests. Computerized data acquisition is used for collecting chamber diagnostics, which include several temperature and solar cell measurements. Electrons were not used in this test.

The list of samples is shown in Table 1. All of the radome-type samples were about 1 in. square. Samples of optical coatings on 1-in.-dia fused-silica discs were also included. The arrangement of the samples in the chamber for this test is shown in Figure 2 along with a photograph in Figure 3. The larger area represents the approximately 12-in. diameter covered by the xenon lamp. The area covered by the deuterium lamp is about 7 in. in diameter so it does not illuminate all samples in the LEO exposure. The solar cell is used as a diagnostic during the exposure to monitor the xenon lamp output. An Optical Solar Reflector (OSR) is present as a check for any contamination if it should condense during the test and might potentially affect test results. There are some samples in Figure 2 that are not in Table 1. Those samples are the subject of a separate report.



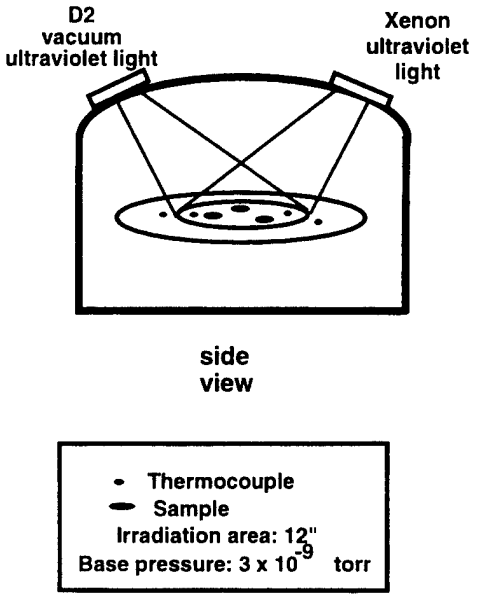


Figure 1. The Space Environment Effects Chamber.

Table 1. List of Samples for LEO Exposure

Sample	Description	Comments	Time Measurements
RDM-208-A	Radome 208 (Good)	Cleaned with Ethyl Acetate	
RDM-208-B	Radome 208 (Good)	Cleaned with IsoPropyl Alcohol	
RDM-208-C	Radome 208 (Good)	Uncleaned	X
RDM-58-A	Radome 58 (Damaged DP-2)	Cleaned with Ethyl Acetate	X
RDM-58-B	Radome 58 (Damaged DP-2)	Cleaned with IsoPropyl Alcohol	X
RDM-58-C	Radome 58 (Damaged DP-2)	Uncleaned	X
RDM-52-A	Radome 52 (Damaged DP-1)	Cleaned with Ethyl Acetate	
RDM-52-B	Radome 52 (Damaged DP-1)	Cleaned with IsoPropyl Alcohol	
RDM-52-C	Radome 52 (Damaged DP-1)	Uncleaned	
RDM-EQM-1	EQM Radome (Good)	Cleaned with Ethyl Acetate	
RDM-EQM-2	EQM Radome (Good)	Cleaned with IsoPropyl Alcohol	
RDM-EQM-3	EQM Radome (Good)	Uncleaned	
RDM-EQMD-1	EQM Radome (Intentionally Damaged)	Cleaned with Ethyl Acetate	
RDM-EQMD-2	EQM Radome (Intentionally Damaged)	Cleaned with IsoPropyl Alcohol	
RDM-EQMD-3	EQM Radome (Intentionally Damaged)	Uncleaned	
RDM-TCW-1	Uncoated Tedlar Radome (Control)		X
RDM-TCW-2	Uncoated Tedlar Radome (Control)		
RDM-TCW-3	Uncoated Tedlar Radome (Control)		
OSR	Optical Solar Reflector	Contamination Monitor	X
A-276	A-276 Paint Sample	Control Sample	X
Solar Cell	Solar Cell	Solar Radiation Monitor	

The Solar UV exposure was started when the chamber pressure was in the low to mid 10^{-8} torr region. The electrons were not included in this test, which was designed only to compare the performance of samples with slightly different histories. During the Solar UV exposure, some samples were removed, and the solar absorptance measured. Samples were removed at 390, 790, 1260, and 1700 equivalent sun-hours. After 3594 equivalent UV sun hours (1288 h, at a solar intensity of 2.8 suns), the exposure was completed, and all samples were removed and measured. Throughout the entire exposure, the deuterium lamp was cycled on periodically (effectively 4.0 h/day) to accumulate approximately the same number of equivalent UV sun-hours as the xenon source. The deuterium source has been estimated to have an initial output of about 17 solar constants over its operating wavelength range, as compared to about 2.8 for the xenon source. The xenon source output is spectrally calibrated pretest using a calibrated spectral radiometer. Relative intensity over the sample area is mapped with a solar cell.

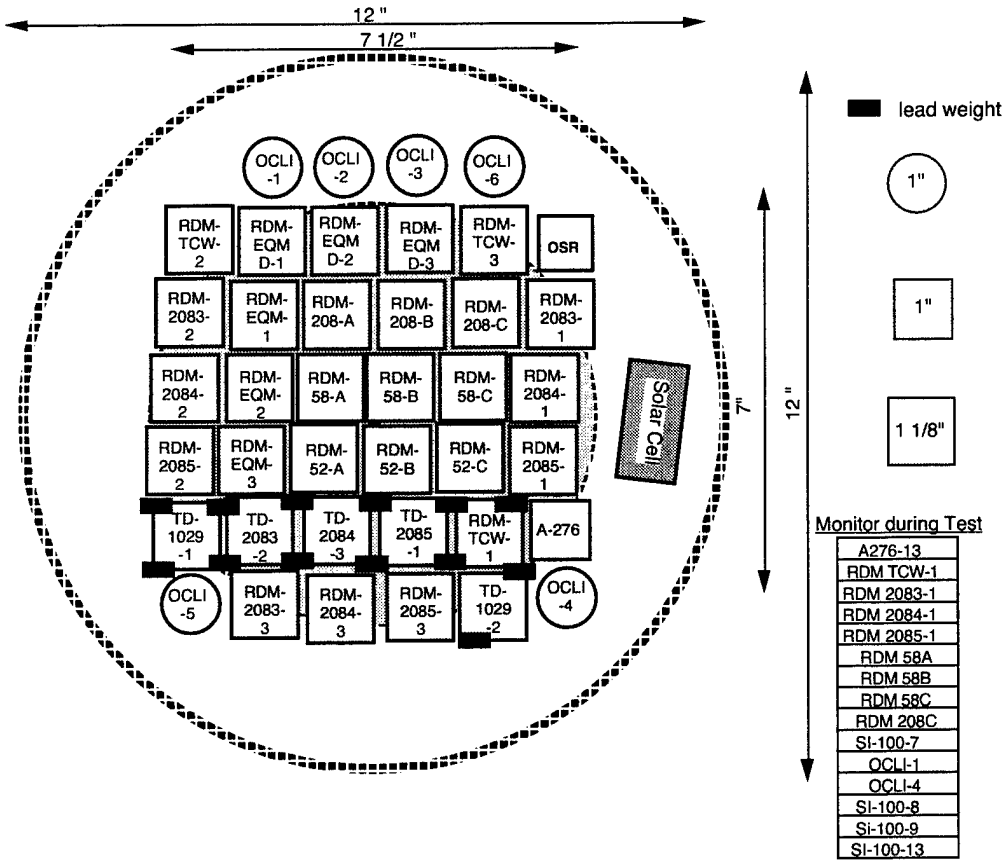


Figure 2. Sample arrangement in the Space Environmental Effects Chamber.

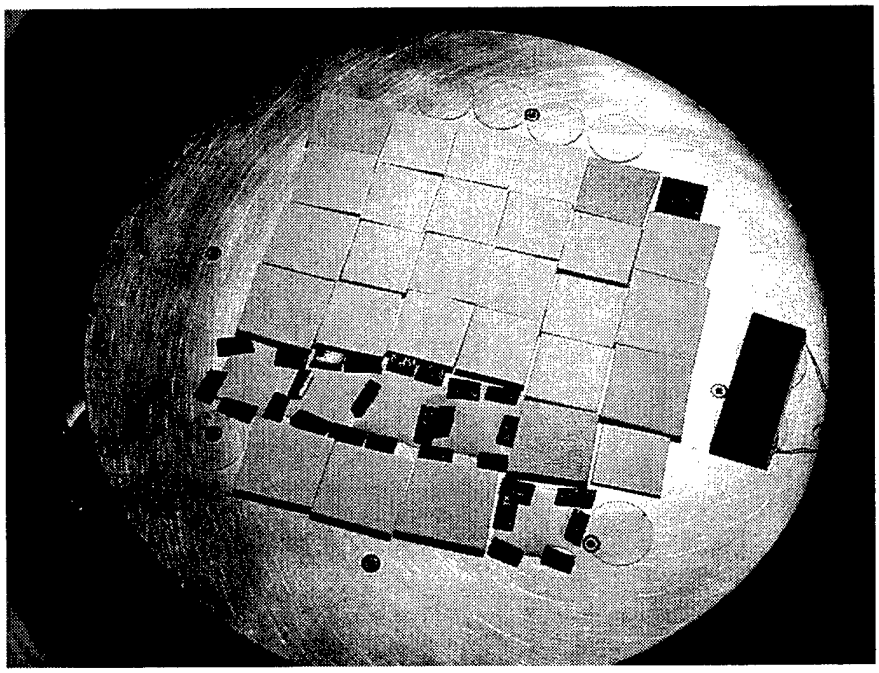


Figure 3. Sample photograph in the Space Environmental Effects Chamber.

The following method was used to obtain the solar reflectance, transmittance, and absorptance. The ultraviolet-visible-near infrared (UV-VIS-NIR) total hemispherical reflectance was measured on a Perkin-Elmer Lambda-9 equipped with a 6-in. Labsphere, Inc. Spectralon-coated integrating sphere. The reflectance measurements were made using a 240 nm/min scan rate, 2-nm slit width, 0.5-s response, with the scan range being 250–2500 nm. The reflectance spectrum was background corrected and referenced to a NIST 2019d White Tile Diffuse Reflectance Standard. This procedure references the sample spectrum to a NIST perfect diffuser rather than the Spectralon integrating sphere coating. Correction factors are calculated and applied to the sample spectrum from the measured NIST Standard. The accuracy of the reflectance measurements is ±2%. A trapezoidal approximation to the two integrals that define the ASTM Solar Air Mass Zero curve and the measured reflectance spectrum is then calculated. The calculation involves 137 points corresponding to the 137 wavelength bins that define the ASTM Solar Air Mass Zero curve from 250 to 2500 nm. The calculation of the solar absorptance makes use of the Kirchoff relationship, which states that any energy (or in this case light) that is not reflected or transmitted, must be absorbed. Therefore, the solar absorptance (α) can be calculated from the hemispherical reflectance (ρ) and diffuse transmittance (τ) by the equation: $\alpha = 1 - \rho - \tau$. If the material is opaque, then the transmittance, τ, is zero, and, therefore, $\alpha = 1 - \rho$.

3. Results

A set of samples was selected to remove and measure during the test in order to monitor degradation as a function of exposure time. The data in Figure 4 show that there is good correlation of the data between this test and a previous test of space environment exposure for the end-of-life response.[1] The A-276 White paint data below 1000 equivalent sun-hours shows some variation compared to the 1997 data, but the end-of-life change in solar absorptance is in excellent agreement. The TCW-1 (Figure 4) should be similar to the TCW20BE3-Radome(1997), but its response is significantly lower. The appearance of this sample was a non-uniform, "blotchy" coloration. The earlier sample turned a uniform brown color. The TCW-1 sample may have either changed or became contaminated during storage and does not have the expected response of an uncoated radome surface.

The data from the selected radome samples is plotted in Figure 5. Sample RDM-208C is representative of an undamaged sample. The RDM 58C sample is one that has seen damage but has not been further cleaned. Its response shows slightly higher degradation than the undamaged sample, which would be expected if some of the coating had been removed. Figure 6 is a SEM photograph of the surface of sample 58C, showing patches where the coating has been removed. The RDM 58A and RDM 58B samples have been cleaned, and the degradation is again slightly higher. This is consistent with some additional damaged coating being removed by the cleaning process.

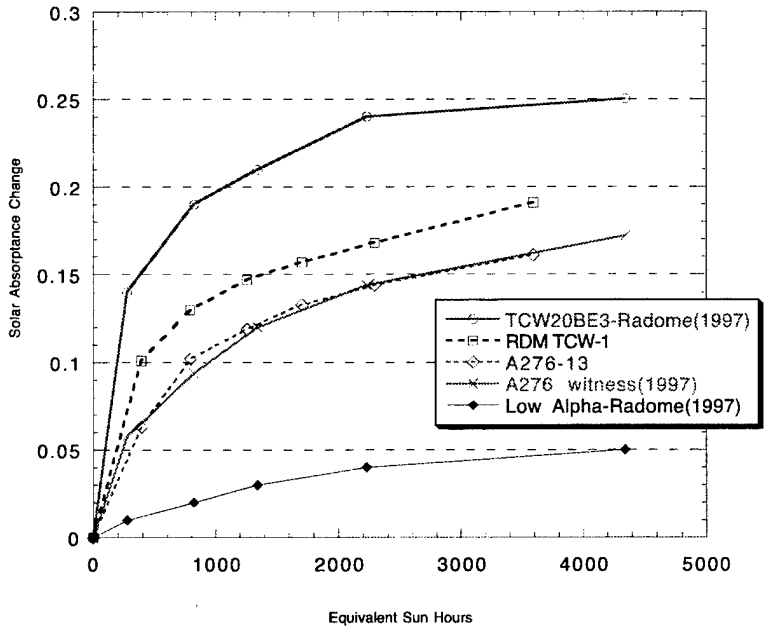


Figure 4. Change in solar absorptance of control samples with exposure time.

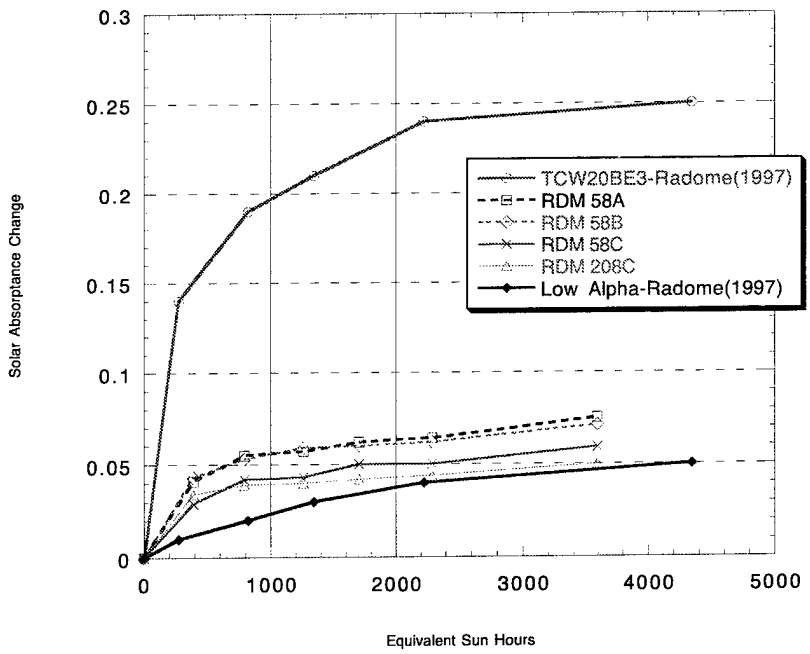


Figure 5. Change in solar absorptance of selected radomes with exposure time.

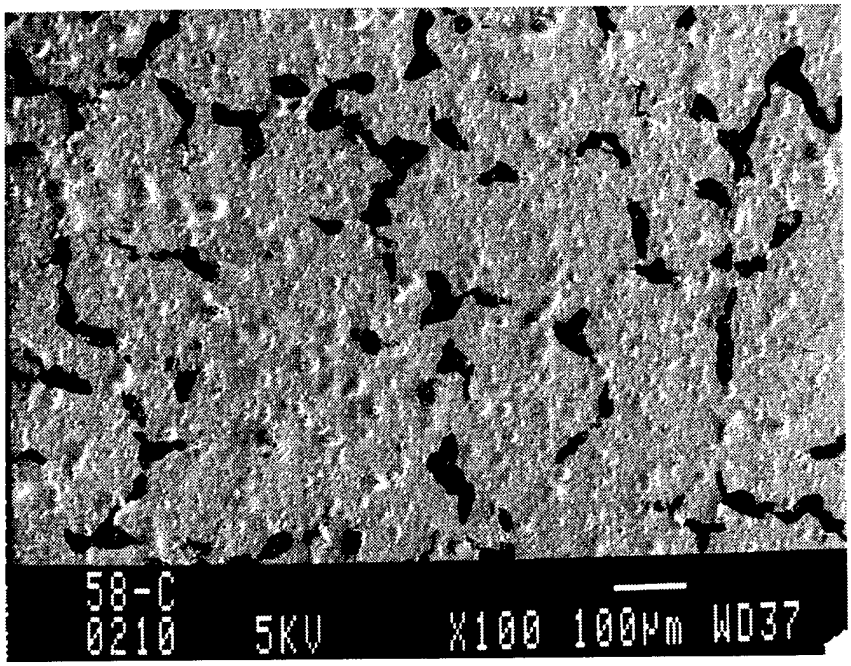


Figure 6. SEM photograph of a water-damaged sample exposed to solar radiation.

The data for solar absorptance for all samples are shown in Table 2 and graphically illustrated in Figure 7. Comparison of the cleaned and uncleaned samples for all samples shows the same trends observed in the samples selected for time monitoring. The damaged samples RDM 52 and RDM 58 show very similar changes in solar absorptance, i.e., about 0.014 higher solar absorptance than the

Table 2. Pretest and Posttest Solar Absorptance of Cleaning Test Samples.

Sample #	Identity	Pretest Alpha	Posttest Alpha	Delta Alpha
RDM 208A	Radome 208/EtOAc	0.190	0.247	0.057
RDM 208B	Radome 208/iPrOH	0.188	0.247	0.059
RDM 208C	Radome 208/unclean	0.188	0.238	0.050
RDM 58A	Radome 58/EtOAc	0.204	0.279	0.075
RDM 58B	Radome 58/iPrOH	0.202	0.273	0.071
RDM 58C	Radome 58/unclean	0.200	0.259	0.059
RDM 52A	Radome 52/EtOAc	0.210	0.286	0.076
RDM 52B	Radome 52/iPrOH	0.209	0.282	0.073
RDM 52C	Radome 52/unclean	0.205	0.264	0.059
RDM EQM A	Radome EQM/EtOAc	0.201	0.25	0.049
RDM EQM B	Radome EQM/iPrOH	0.203	0.248	0.045
RDM EQM C	Radome EQM/unclean	0.203	0.247	0.044
RDM EQMD A	Radome EQMD/EtOAc	0.202	0.245	0.043
RDM EQMD B	Radome EQMD/iPrOH	0.203	0.256	0.053
RDM EQMD C	Radome EQMD/unclean	0.203	0.252	0.049
RDM TCW-1	Uncoated Tedlar Radome	0.241	0.432	0.191
RDM TCW-2	Uncoated Tedlar Radome	0.236	0.404	0.168
RDM TCW-3	Uncoated Tedlar Radome	0.239	0.457	0.218
A276-13	Chemglaze A-276	0.257	0.418	0.161
SI-100-7	OCLI OSR	0.078	0.080	0.002
Si-100-8	OCLI OSR	0.071	0.086	0.015
SI-100-9	OCLI OSR	0.084	0.081	-0.003
SI-100-13	OCLI OSR	0.091	0.084	-0.007

uncleaned samples. Samples RDM-208 and RDM-EQM represent apparently undamaged samples, but the results indicate changes in final solar absorptance from the cleaning process of about 0.06 and 0.05, respectively. The RDM-EQMD samples were samples of RDM-EQM that had been intentionally damaged by direct exposure to water droplets. It would appear that the water exposure on these samples did not affect either the initial or the end-of-life alpha's. The data from RDM-EQM and RDM-EQMD suggest that any change due to cleaning of these samples is negligible and probably within experimental error. However, the data from RDM 52 and RDM 58 samples indicate that cleaning the radomes inadvertently damaged during testing is likely to cause increases in end-of-life alphas. This is probably due to removal of damaged coating during the cleaning process. Simple exposure to water does not seem to produce effects of the same magnitude.

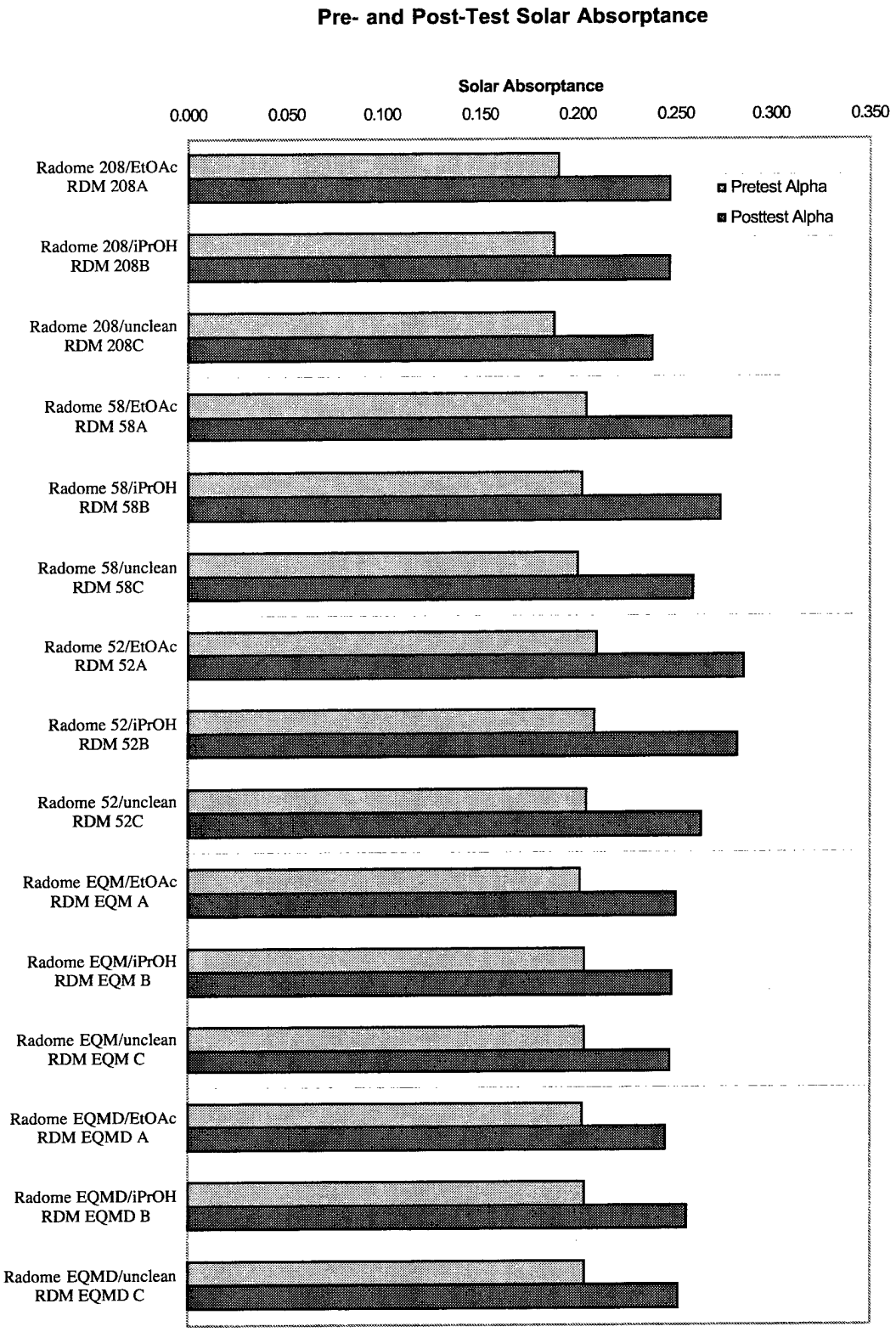


Figure 7. Bar graph display of solar absorptance data.

4. Conclusions

Water exposure of a Cloud White Tedlar surface with the Low Alpha Coating applied by OCLI can lead to localized damage to the coating. The damage exposes the Tedlar to the solar UV radiation, which has been shown to severely degrade the solar absorptance of the Tedlar material. In addition, there are areas where the coating may be delaminated, but the coating is still attached. Wiping the surface with a cloth moistened with a solvent would be expected to remove loosely adhered coating and further degrade the stability of the material. If the coating is present, even if not strongly adhered, it would protect the Tedlar. This test was undertaken to evaluate whether the cleaning of a surface with this type of damage would have an unacceptable effect on the end-of-life solar absorptance of hardware ready for flight.

Cleaning a damaged radome surface (such as radomes 58 or 52) increases end-of-life solar absorptance by about 0.014. Smaller values, on the order of 0.008, are observed for undamaged radome surfaces such as radomes 208. The uncoated radome sample, TCW-1, shows an increase in alpha of 0.191, but 0.245 would be the expected increase for an uncoated sample from the earlier test. An undamaged and uncleaned radome surface, such as EQM C, shows a delta alpha of 0.044 after UV exposure. Comparing these two values gives a difference of 0.201 for the amount of protection afforded the Tedlar by an undamaged coating. Ratioing the 0.014 increase in alpha for cleaning a damaged radome surface with this value of 0.201 indicates that roughly an additional 7% loss of coating occurred due to cleaning. For radomes installed on the hardware, cleaning would result in a final end-of-life solar absorptance of about 0.28 due to UV exposure.

An end-of-life solar absorptance of about 0.28 for the damage on these samples probably does not represent an appreciable degradation above the expected end-of-life solar absorptance of an undamaged radome of about 0.25. The solar radiation is not the only contributor to the end-of-life value of solar absorptance. Exposure to electrons for a five-year LEO dose is expected to add roughly 0.02 alpha. Some of this degradation could be offset by atomic oxygen, perhaps as much as –0.03 alpha. Contamination accumulation on the surface would increase solar absorptance, and there is a contamination budget to control that contribution. Any other defects or anomalies like bubbles or wrinkling in the coating would also add to the solar absorptance. The calculation of solar absorptance can also vary due to calibration methods and the extrapolation of the measured data (about 98% of the solar spectrum) to the full solar spectrum. The final expected value would be additive of all contributors.

Reference

1. W. K. Stuckey and M. J. Meshishnek, "Space Environmental Stability of Tedlar with Multi-Layer Dielectric Coatings: Space Simulation Testing Results", *Proceedings of the 5th International Symposium on Materials in a Space Environment*, Arcachon, France, 5-9 June 2000, TR-2000(8565)-8 August 20, 2000

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